NACA TN No. 1645

8123

TECH LIBRARY KAFB, NM
0144957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1645

A STATISTICAL ANALYSIS OF GUST-VELOCITY MEASUREMENTS AS AFFECTED BY PILOTS AND AIRPLANES

By Harry Press

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington
June 1948

AFWL
TECHNICAL LIBRARY

TECH LIBRARY KAFB, NM
0144957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1645

A STATISTICAL ANALYSIS OF GUST-VELOCITY MEASUREMENTS AS AFFECTED BY PILOTS AND AIRPLANES

By Harry Press

SUMMARY

Gust data obtained during the U. S. Weather Bureau thunderstorm project at Orlando, Fla. in 1946 were analyzed statistically to determine the effects on the gust measurements of the several pilots and the several airplanes of the same model. The results indicate that, for three of the pilots and two of the airplanes, the effects on the gust measurements may introduce average errors of about ±10 percent. The causes of these effects are not explained at present and the need for additional work on this problem is indicated.

INTRODUCTION

The measured reactions of an airplane in flight through gusty air have been used extensively by the National Advisory Committee for Aeronautics and others to obtain information on the structure and the intensity of atmospheric gusts. The simplifying concepts of a sharp-edged gust and the effective gust velocity (reference 1) have proved useful in the investigation of gust loads on airplanes. Measurements of gust intensity obtained to date on this basis have been found of wide use and are the basis for present gust load design criterions.

It has been assumed in the past that the influence of piloting technique and the airplane characteristics on the measurements of effective gust velocity are consistent in sign and magnitude. Little information has been available on the magnitude of these effects although various unpublished estimates have indicated that the pilot effect may vary anywhere from 0 to 100 percent. Gust data have been obtained to date by a variety of airplane types (reference 2). The lack of control over the test conditions for these flights (such as weather, pilot technique, and operating practices) obscure the possible influence of the pilot and airplane on the data.

The problems of pilot and airplane effects on the gust data become of appreciable importance in studies which utilize several pilots and airplanes, inasmuch as it is desirable that the data obtained be homogeneous and comparable. The 1946 operations of the thunderstorm project (reference 3) utilized 12 pilots of similar training and

10 airplanes of the same model for flight surveys of afternoon convective thunderstorms. The problems of pilot and airplane effects were recognized and considerable effort was made in the planning of the project to minimize these effects. On the basis that the gust data obtained by each of the pilots and each of the airplanes are representative samples, preliminary estimates may be obtained of the errors in gust measurements introduced by differences in piloting technique and by differences between airplanes of the same type.

SCOPE AND SELECTION OF DATA

The data obtained from the 1946 operations of the thunderstorm project included gust data from flight surveys of 38 storms. Briefly, the storm surveys consisted of simultaneous traverses of the storm clouds at five altitudes from 6,000 to 26,000 feet for a total of 485 traverses. The distribution of these traverses by airplane and pilot is given in table I.

The maximum positive and negative effective gust velocities $U_{e_{max}}$ as evaluated in the manner of reference 3 were used as a measure of the gust intensity for a given traverse. Inasmuch as the higher gust velocities are of particular interest for gust-load problems, the selection of these data provided a simple and convenient method of selecting a homogeneous sample which included a large majority of the higher gust velocities. The distributions of the maximum positive and negative gust velocities obtained for each pilot and for each airplane were then combined on the assumption that they are equal, and the combined distributions were then taken as a measure of their gust experience. The results, classified by pilot and airplane, are shown in tables II and III, respectively. Since the data available for airplanes 8, 9, and 10 were considered insufficient for the present analysis, these data were omitted from table III and the analysis for the airplanes was restricted to the seven remaining airplanes.

STATISTICAL CONSIDERATIONS

In order to arrive at a reasonable basis for direct comparison of the gust experience of the pilots and the airplanes, the following assumptions are made:

(1) The flight assignments of airplane and pilot are random and are independent.

(2) The effects of extraneous factors such as altitude, storm intensity, and stage of storm development are random.

(3) The size of the samples is sufficiently large so that the effects of the extraneous factors are largely averaged out.

For the thunderstorm flights, the intentions were that the pilots and the airplanes were to receive assignments at random, but operating limitations prevented complete randomization. Although it can hardly be expected that the distribution of traverses by airplane and pilot given in table I completely satisfies assumption (1), it is evident that each of the pilots flew most of the airplanes. Inasmuch as the departures from random assignments of airplanes and pilots resulted from conditions which might not be expected to affect seriously the validity of the present comparisons, assumption (1) would appear reasonable.

Other pertinent factors, such as storm intensity, altitude of traverse, and stage of storm development were selected in no fixed manner which might be expected to affect the validity of the present comparisons. Simple checks indicated that the intensity of the storms in which the various pilots and airplanes flew varied within narrow limits and did not appear to prejudice the data. Similar checks for the altitude flown indicated that the traverses for each of the pilots and each of the airplanes were, in general, well distributed over the several altitudes. Little information is available regarding the stages of storm development during the times of the traverses although almost all the flights were known to be made in the later stages of storm development. In view of these considerations, the assumption that these factors had no significant effects on the data appeared reasonable.

The proper size of the samples necessary to yield a reliable distribution is a difficult problem. On the basis of experience with these data, a minimum sample size of 25 traverses is considered necessary to yield reliable results.

METHOD OF ANALYSIS AND RESULTS

The analysis of the frequency distributions of the type shown in tables II and III is a twofold problem consisting of the determination of the statistical significance of the observed differences and the evaluation of the character and magnitude of these differences. In order to test whether the observed differences between the distributions represent real differences or merely random sampling fluctuations, the chi-square test (reference 4, pp. 164–171) provides a useful test of homogeniety. In addition, the irregularities of the present data may be smoothed out by fitting frequency-distribution curves. The parameters of these curves may be used to define the characteristics of the distributions. Standard statistical tests may then be used to determine the significance of the differences in the values of the parameters. Differences in the values of the parameters also provide a measure of the magnitude of the variations.

In order to apply the methods of analysis outlined in the preceding paragraph to the present data, chi-square tests were made between the distributions for the various pilots and the various airplanes. Pearson Type III probability curves (reference 4, pp. 46-58) were then fitted to the gust velocity distributions of tables II and III. The results obtained from the data for the pilots and airplanes are shown in figures 1 and 2, respectively. These curves indicate the probability that the maximum positive and maximum negative gust velocities for a given traverse will exceed the values indicated. Tests of goodness of fit for these curves indicate that they give a satisfactory representation of the data. The computed values of the statistical parameters for the curves of figures 1 and 2 are shown in tables II and III, respectively.

Since it has been noted that the parameters define the curves, a brief consideration of the relationship between the curves and parameters appears pertinent. In general, differences in mean values for the distributions are largely reflected in the lateral position of the probability curves, with an increase in mean value moving the curve to the right. Differences in standard deviation and skewness show up by a change in curve shape with the main effect of an increased standard deviation reflected by a smaller absolute value of the slope and a greater probability of exceeding the higher gust velocites. A change in skewness shows up largely by a divergence of the right-hand tails of the present curves. Increased skewness also gives greater probabilities of exceeding given values of gust velocities.

DISCUSSION

Pilots

Inspection of figure 1 indicates that wide scatter exists between the distributions for the various pilots. Application of the chi-square tests to the distributions given in table II indicated that the differences between the distributions for the pilots are, in most cases, statistically significant. The curves for the various pilots have wide scatter at gust velocities above 20 feet per second. The distribution for pilot M indicates the highest probability for exceeding the values of gust velocities above 20 feet per second. On the average, the gust velocity that may be expected to be exceeded once in a negative and once in a positive direction in 100 traverses varies from 24 feet per second for pilot C to about 39 feet per second when extrapolated for pilot M. These wide variations should indicate that, at highest gust velocities, the pilot effects may well be critical.

Consideration of the statistical parameters of table II indicates that, in most cases, the magnitude of the differences is small. The largest difference in mean values of $U_{e_{max}}$ between two pilots, as exemplified by pilots A and E, is given by a mean value of 15.00 feet per second as compared with 12.22 feet per second. Inasmuch as the

over-all mean for all pilots is 13.56 feet per second, these values represent differences of about ±10 percent. If these differences in mean values are taken as the average errors introduced by the pilots, they represent additional sources of error of engineering concern. Differences in the standard deviations of the distributions do not appear significant with the exception that the distribution for pilot M had a standard deviation that was about twice the value obtained for the over-all pilot distribution. This result, however, may be purely fortuitous as this pilot made the fewest traverses. The differences between the coefficients of skewness for the distributions for the pilots appear appreciable in several cases and indicate that pilot effects are possibly a function of gust velocity, with pilot effect increasing at higher gust velocities.

Airplanes

Inspection of figure 2 indicates that little scatter exists between the distributions for most of the airplanes although the differences between the distributions for two of the airplanes (airplanes 5 and 7) appear appreciable at the higher gust velocities. These observations are borne out by the application of the chi-square tests to the frequency distributions of table III which indicated that the distributions for these two airplanes are significantly different from each other as well as from the other airplanes. Differences among the distributions for the other airplanes are, in general, not significant. Figure 2 indicates that the gust velocity that may be expected to be exceeded once in 100 traverses varies from about 26 feet per second for airplane 5 to about 32 feet per second for airplane 7. The corresponding gust velocities for the remaining airplane are closely grouped from 28.5 feet per second to 30.0 feet per second.

Consideration of the values of the parameters of table III indicates that the marked differences between the curves for airplanes 5 and 7 result largely from the differences in mean values whereas at the higher gust velocities the differences are amplified by the observed differences in skewness. The mean values of $U_{e_{max}}$ for these airplanes are 12.55 feet per second and 15.53 feet per second, respectively. The indicated difference of about 25 percent between these values is statistically significant and clearly of importance. Since the over-all mean value of $U_{e_{max}}$ for all airplanes is 13.51 feet per second, the mean values for airplanes 5 and 7 represent differences of about −7 percent and 14 percent, respectively. The lowest mean value of $U_{e_{max}}$ was 11.82 feet per second for airplane 1. This value is about 12 percent lower than the over-all mean for all airplanes. Because of the effects of the values of the other parameters, however, the probabilities of encountering the higher gust velocities, for this airplane, show no unusual tendencies.

If the differences in mean values of $U_{e_{max}}$ are taken as the average errors introduced by the airplanes, they represent additional sources of error which in two cases are greater than ±10 percent. Inasmuch as all the airplanes were of the same model and were similarly loaded, the present differences are of concern. No information is, however, available at the present time on the causes for these large disparities.

Implications

In view of the number of airplanes and pilots used in the thunderstorm project and the small magnitude of the differences between distribution for most of the airplanes and most of the pilots, it may be expected that, for the over-all analysis of the thunderstorm project gust data, the pilot and the airplane effects would be largely averaged out. The differences noted between two of the airplanes and several of the pilots are, however, of sufficient magnitude to be of concern when individual airplane and pilot data are analyzed. For detailed analysis of these data and in the absence of better information, adjustment of the data for pilot and airplane effects based on the departure of specific pilot and airplane data from the over-all gust measurements may be advisable. The differences in the distributions of effective gust velocity for two of the seven airplanes and for three of the pilots suggest that the pilot and airplane effects may be appreciably amplified when different type airplanes and pilots of different training are utliized.

Past design practices have recognized the problems of pilot and airplane effects in that the calculation of design gust loads for new airplanes is essentially the transfer of measured loads from a reference airplane to the new design. Such a transfer of loads includes, roughly, the effect of pilot and airplane characteristics. The inaccuracy of this procedure may prove to be of concern in the design of airplanes that are significantly different in characteristics from the reference airplane.

CONCLUDING REMARKS

A statistical analysis of the gust data obtained during the U. S. Weather Bureau thunderstorm project as affected by pilots and airplanes has indicated the following:

1. The effects of airplane and pilot characteristics appear to influence the gust measurements obtained during the thunderstorm project. The results indicate that, for three of the pilots and two of the airplanes, the effects may introduce average sources of error of about ±10 percent.

2. For an over-all analysis of the thunderstorm project gust data in which the data obtained by several airplanes and several pilots

are combined, the airplane and pilot effects can be expected to be largely averaged out. For analysis of individual traverse data, these effects may be of sufficient magnitude to be of concern.

3. The magnitude of the effects noted for several of the pilots and two of the seven airplanes for the present data suggests that the effects of airplane and pilot on gust and gust load measurement may be appreciably greater for other pilots and airplanes of different types. Further investigation is needed in order to determine the magnitude and causes of these effects and to develop methods of incorporating these effects into predicted gust load factors.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., March 29, 1948

REFERENCES

1. Rhode, Richard V.: Gust Loads on Airplanes. SAE Jour., vol. 40, no. 3, March 1937, pp. 81–88.

2. Rhode, Richard V., and Donely, Philip: Frequency of Occurrence of Atmospheric Gusts and of Related Loads on Airplane Structures. NACA ARR No. L4I21, 1944.

3. Tolefson, Harold B.: Preliminary Analysis of NACA Measurements of Atmospheric Turbulence within a Thunderstorm – U. S. Weather Bureau Thunderstorm Project. NACA TN No. 1233, 1947.

4. Kenney, John F.: Mathematics of Statistics. Pt. II. D. Van Nostrand Co., Inc., 1939.

TABLE I

NUMBER OF TRAVERSES MADE BY EACH PILOT

AND EACH AIRPLANE

Pilot	Airplane										Total
	1	2	3	4	5	6	7	8	9	10	
A	10	11	15		1	4					41
B			4	11	6	9	7		3		40
C	5	12			4	4	4		6		35
D		4	11		10	5	9		3		42
E	4		5	5	5	8					27
F		25	7	12			9	4			57
G		9	18	4		12	4		4		51
H	4	1		12	9	4	1	3	5	7	46
J	10	11	5	9	11		4				50
K	5	5	8	3		4				4	29
L	5	1	5		8	12	9			3	43
M	4	3	3	8		6					24
Total	47	82	81	64	54	68	47	7	21	14	485

TABLE II

FREQUENCY DISTRIBUTION OF MAXIMUM EFFECTIVE GUST VELOCITY BY PILOTS

$U_{e_{max}}$ (fps)	Pilot												Total
	A	B	C	D	E	F	G	H	J	K	L	M	
2 to 4	1	1						1	1	1	8	1	14
4 to 6	7	5	1	5	1	1	8	1	1		5	5	40
6 to 8	9	11	5	7		12	8	17	8	5	8	9	99
8 to 10	13	15	12	11	8	10	7	12	12	8	11	9	128
10 to 12	12	8	15	8	10	19	13	14	13	12	16	1	141
12 to 14	13	11	6	18	7	18	12	12	14	12	9	5	137
14 to 16	8	6	9	9	7	22	19	7	17	3	8	2	117
16 to 18	8	6	5	7	4	8	12	11	11	5	6	2	85
18 to 20	7	5	10	5	7	14	11	8	12	2	4	3	88
20 to 22	2	2	6	4	4	5	7	4	3	3	5	2	47
22 to 24		2		5	4	3	1	1	2	2	2	2	24
24 to 26	1	1	1	1	2	1	2	2		4	2	2	19
26 to 28	1	2		1			1		2		2	1	10
28 to 30		2		3		1		2					8
30 to 32							1		3	1		1	6
32 to 34												1	1
34 to 36		1											1
36 to 38													0
38 to 40												1	1
Total	82	78	70	84	54	114	102	92	47	99	58	86	966
Mean	12.22	13.05	13.60	14.07	15.00	13.88	14.06	13.09	14.37	13.90	12.21	13.55	13.56
Standard deviation	4.89	6.45	4.60	5.85	4.92	4.56	5.30	5.36	5.45	5.66	5.96	8.29	5.63
Coefficient of skewness	0.496	1.102	0.324	0.662	0.304	0.462	0.288	0.740	0.826	0.892	0.494	1.113	0.701

TABLE III

FREQUENCY DISTRIBUTION OF MAXIMUM EFFECTIVE GUST VELOCITY BY AIRPLANES

$U_{e_{max}}$ (fps)	Airplane							Total
	1	2	3	4	5	6	7	
2 to 4	4	2		1	6	1		14
4 to 6	5	4	9	9	5	3	2	37
6 to 8	11	12	22	16	12	12	7	92
8 to 10	17	15	25	20	20	21	5	123
10 to 12	18	27	24	12	12	17	13	123
12 to 14	16	15	22	16	11	24	16	120
14 to 16	8	33	17	18	7	17	14	114
16 to 18	3	15	16	16	10	9	6	75
18 to 20	4	21	12	7	16	7	14	81
20 to 22		5	7	4	4	11	4	35
22 to 24	3	5	1	1	3	6	5	24
24 to 26	1	6	3	3		3	2	18
26 to 28	2	2				3	2	9
28 to 30		1		2	1	2	2	8
30 to 32	1		3	1			1	6
32 to 34		1						1
34 to 36							1	1
36 to 38								0
38 to 40				1				1
Total	93	164	161	127	107	136	94	882
Mean	11.82	14.46	12.84	13.11	12.55	14.07	15.53	13.51
Standard deviation	5.40	5.39	5.31	5.95	5.54	5.61	5.94	5.69
Coefficient of skewness	1.15	0.46	0.92	1.14	0.28	0.61	0.73	0.72

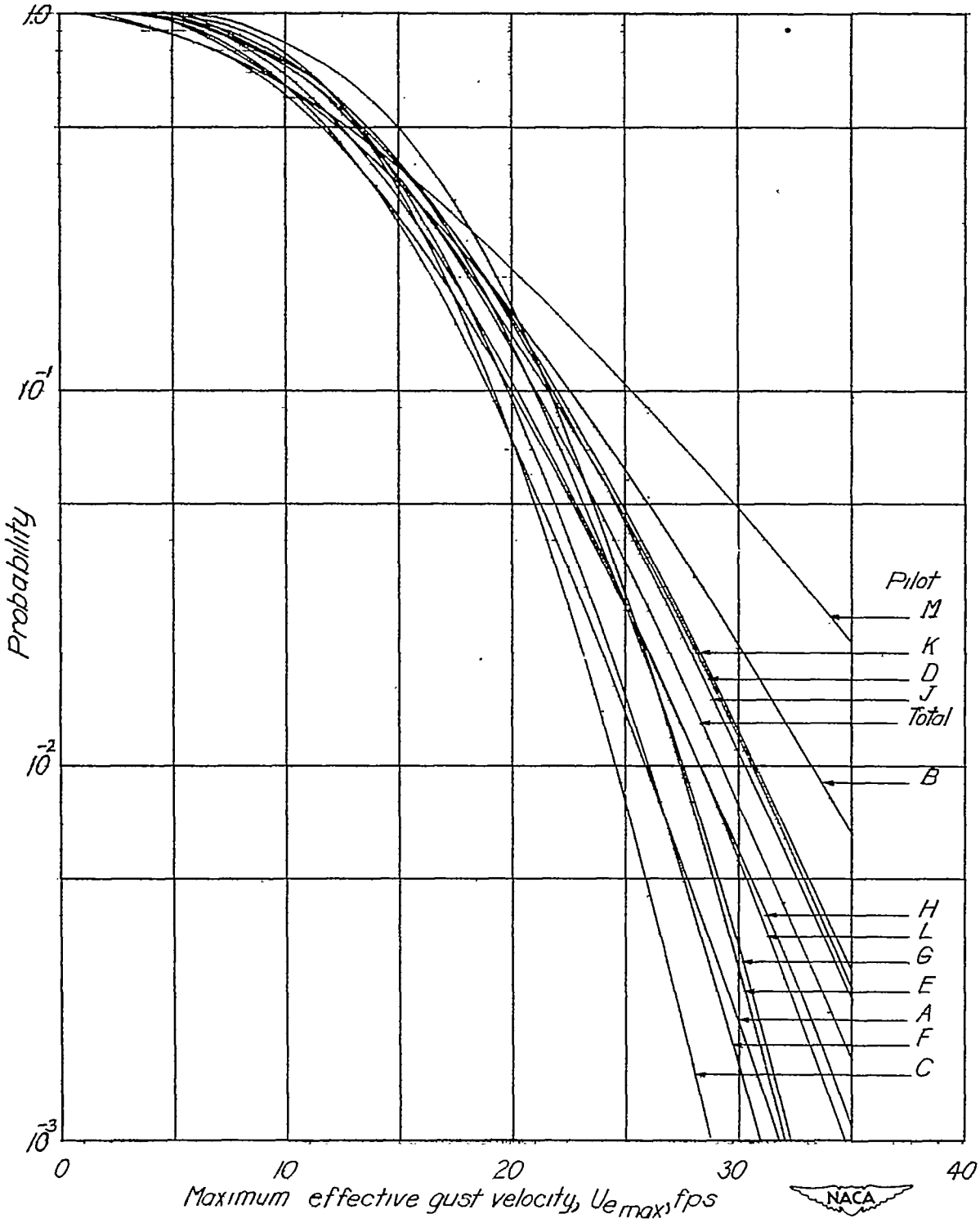

Figure 1.- Probability that the maximum effective gust velocity for a given traverse will exceed the indicated value. Pilots.

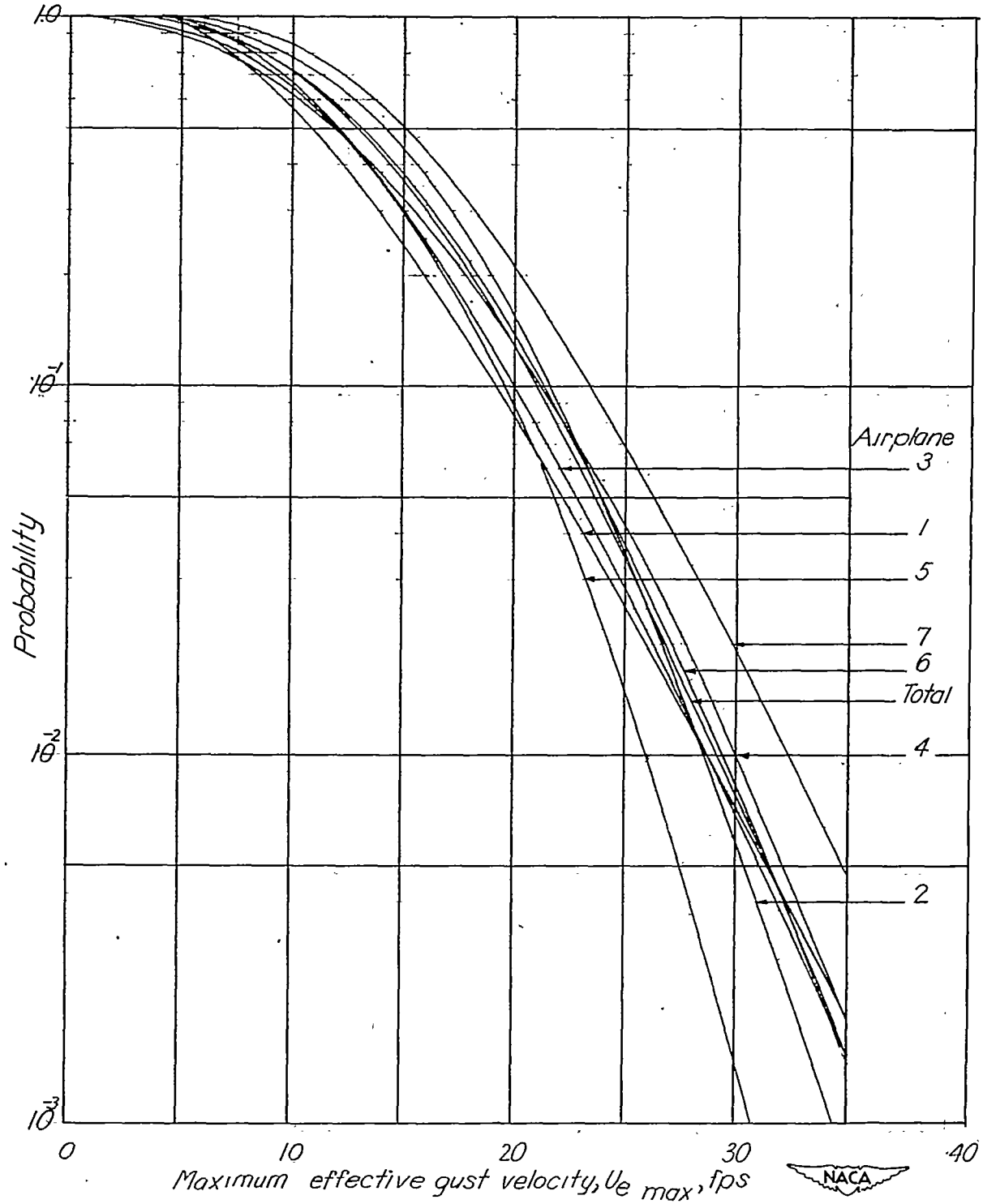

Figure 2.- Probability that the maximum effective gust velocity for a given traverse will exceed the indicated value. Airplanes.